Effects of Mineral and Petroleum Extraction on Living Resources of Continental Shelf Waters

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Abstract

One of the potentially serious problems that may accompany mineral and oil production from a continental shelf is the possibility of damage to living resources of the sea. Most of the fish taken in North American waters are caught on or over continental shelf areas, and any major interference or pollution would significantly affect the American fishing industry.

The first section of this paper summarizes current information on actual and potential production of fish and shellfish from each of the major segments of the continental shelf adjacent to the United States. The second deals with the types of conflict that may arise between fishermen and those exploring for or producing oil or minerals from the shelf. The final section evaluates in qualitative terms some of the indirect effects stemming from expanded petroleum and mineral activity in offshore waters that may be of real benefit to the producers of seafood.

The degree to which the conflicts are minimized and the benefits maximized depends critically on the ability of both parties to plan expansion jointly and to exchange technological and scientific knowledge.

I. INTRODUCTION*

UNTIL FAIRLY RECENTLY the living resources of the sea were peculiarly the province of commercial fishermen and a host of natural predators with whom they waged more or less intermittent warfare. This is not to say that the commercial exploitation of United States fish and shellfish for continental shelf waters was peaceful or orderly. On the contrary, today's incredible hodge podge of conflicting and restrictive "conservation" legislation is mute testimony to the bitterness with which fishermen from different areas or using different kinds of gear have fought over the spoils. The results of this internal warfare on good management practice have been devastating.

In more recent decades, conflict between commercial and sport fishermen has grown to serious proportions. As in the case of much of the bickering among commercials, the conflict has frequently been more apparent than real, and group interest, rather than general public interest, is the objective. The effects, in terms of legislation designed to hamper one or the other of the two contestants, have been equally inimical to good fishery management.

Now a new contender for access to resources on the continental shelf has entered the field in the form of petroleum and mineral producers. As before,

*For simplicity, the term "mineral" hereafter will encompass petroleum and gas. Similarly, "fishery" is assumed to include shellfish operations. The term "conflict" is also construed rather broadly to include not only pollution in the familiar sense of the word but also other forms of physical interference that would prevent or increase the cost of harvesting fish and shellfish.

the hue and cry about harmful effects has reached a crescendo long before the facts were established—either by casual observation or scientific investigation. With the lessons of the past before us, it is to be hoped that this new type of conflict in the sea can be resolved on an orderly basis without giving rise to another layer of pressure-born restrictive legislation, the ultimate effect of which is to hamper all uses of marine resources.

This paper is addressed to the following questions: What are the actual magnitudes involved in the potential conflict between mineral exploration and production and fisheries? In what specific ways may mineral exploration and recovery techniques, actual and potential, encroach on the use of living resources? To what extent can these conflicts be ameliorated by mutual adjustment? What basis of choice can be developed to deal with cases where the conflict is real and where public authority must therefore make allocation decisions?

It should be made clear at the outset that conflicts in the use of natural resources do not make the marine environment unique in any sense. With only trivial exceptions, all resources, human and material, have multiple uses, and every society must find ways of allocating each to the use or uses where its greatest contribution can be realized. For the overwhelming majority of natural resource inputs, this task is accomplished by the market mechanism in the United States. Owners or lessors of natural resources, in maximizing the returns available to them from alternative uses, will also act in the best interest of society, provided that: (1) markets in which the transactions occur are reasonably competitive and (2) all benefits and costs accrue to the producer responsible for them. The possibility of mutually destructive competition among users of the living and non-living resources of the sea and seabed arises out of imperfections in legal arrangements that makes this highly efficient and economical process of decision-making inapplicable. It is impossible to establish property rights in the usual sense over living marine resources, and the producer of non-living resources may inflict "external costs" on fishermen (and the general public) for which he cannot be held accountable except through some form of public intervention. The dismal record of pollution of fresh water and air suggests the need to move swiftly lest we repeat the same mistakes in the marine environment.

II. THE COSTS OF CONFLICT

A. Living resources

Living resources of the sea are becoming increasingly important in an economic sense and, as rapidly expanding world populations look to the oceans as a source of food, their political and sociological "weight" may increase even more.

At present most of the fish taken in North American waters are caught on or over areas of the continental shelf. The character and extent of the continental shelf of the United States, therefore, play a major role in determining the level and composition of the United States fishing industry. Table 1 provides an approximation of the continental shelf areas in nautical square miles adjacent to major geological, rather than legal, subdivisions of the United States. The extensive shelf areas adjacent to the nation are mainly in the Bering Sea and Gulf of Mexico, with moderately extended shelf areas in the central Gulf of Alaska and off the New England states.

TABLE 1

APPROXIMATE AREA OF CONTINENTAL SHELF AND UPPER SLOPE
(in nautical square miles)

Areas	Fathoms 1-100	Fathoms 101-300
New England	77,600	22,500
Middle and South Atlantic	79,000	143,000
Gulf of Mexico	112,000	45,000
Eastern Bering Sea	145,000	14,000
Gulf of Alaska	60,000	15,000
Oregon and Washington	7,300	2,800
California	23,100	5,600
Hawaii	3,900	4,300

1. CURRENT PRODUCTION

The general dimensions of the American fishing industry are indicated in Tables 2 and 3. Several essential characteristics of the United States flag fisheries stand out clearly in these data. Most apparent is the absence of growth; landings have been virtually stable at between 4 and 5 billion pounds for the past 3 decades. Meanwhile, world production of fish and shellfish has climbed from about 20 million metric tons in 1950 to 57 million tons in 1966. American consumption has also expanded rapidly, but the entire gross increase has been met from imports. The relative decline in the position of the United States fleet has been even greater with respect to landings used directly for human food.

It is also evident that there are major differences in the regional composition of catches. New England landings consist largely of groundfish and shellfish entering the fresh frozen trade. High valued salmon, tuna, crabs and oysters dominate the catch in the Pacific Coast states; groundfish assumed much greater importance after 1940, but have leveled off in recent years. Catches in the Middle and South Atlantic and Gulf areas are dominated in terms of

TABLE 2

SUMMARY OF CATCH BY REGION, 1966
(million pounds and dollars)

Region	Quantity	Value
New England	684	$ 78
Middle Atlantic	168	22
Chesapeake	502	35
South Atlantic	368	27
Gulf	1,196	123
Pacific	1,254	168
Great Lakes	69	6
Mississippi River and tributaries	112	10
Hawaii	13	3
Totals	4,366	$472

Source: U.S. Department of the Interior, Bureau of Commercial Fisheries, *Fishery Statistics of the United States*, 1966. U.S. Government Printing Office, Washington, D.C. 1968.

TABLE 3

UTILIZATION OF FISHERY PRODUCTS IN THE UNITED STATES FOR SELECTED YEARS, 1945-1967

	1945	1950	1955	1960	1965	1967
Population, Millions[1]	129.1	150.2	162.3	1,782	191.9	195.7
	Edible Fish (round weight)					
Domestic Catch, Million lbs.	3,167	3,307	2,579	2,498	2,586	2,385
Imports, Million lbs.[3]	680	1,128	1,332	1,766	2,576	2,683
Total, Million lbs.	3,847	4,435	3,911	4,264	5,162	5,068
Per Capita Use, lbs.	29.8	29.5	24.1	23.9	26.9	25.9
(meat weight)[2]	(9.9)	(11.8)	(10.5)	(10.3)	(10.9)	(10.6)
	Industrial Fish (round weight)					
Domestic Catch, Million lbs.	1,431	1,594	2,230	2,444	2,190	1,677
Imports, Million lbs.[4]	31	639	980	1,515	3,182	7,442
Total, Million lbs.	1,462	2,233	3,210	3,959	5,372	9,119
Per Capita Use, lbs.	11.3	14.9	19.8	22.2	28.0	46.6
	Total Fish (round weight)					
Domestic Catch, Million lbs.	4,598	4,901	4,809	4,942	4,776	4,062
Imports, Million lbs.	711	1,767	2,312	3,281	5,758	10,125
Total, Million lbs.	5,309	6,668	7,121	8,223	10,534	14,187
Per Capita Use, lbs.	41.1	44.4	43.9	46.1	54.9	72.5

1 July 1 population eating from civilian supplies, excluding armed forces overseas: beginning 1950—50 states.
2 Computed per capita consumption on edible or meat weight basis with allowances for exports and changes in beginning and end-of-year stocks.
3 Estimate based on 1946 relationship of round to imported product weight.
4 Estimate based on the 1946 ratio of round weight to industrial product weight.

SOURCE: Office of Program Planning, Bureau of Commercial Fisheries.

volume by landings of industrial fish (principally menhaden) used for meal and oil, but these areas also produce large quantities of valuable shrimp, oysters and crabs for the fresh and frozen market. The inshore fisheries of Hawaii are very small and stable; the bulk of the catch by weight and value comes from tuna.

The fisheries of the United States as a whole are heavily oriented to species taken on or above the continental shelf. It is estimated that total non-shelf production accounts for no more than 10% by weight and 15% by value, most of it consisting of tuna and tuna-like species. Although literally hundreds of individual species are exploited commercially, few are of real importance; eight groups—salmon, shrimp, tuna, groundfish, menhaden, crabs, oysters and halibut—accounted for more than 60% of the total United States catch value in recent years.

As indicated in Table 4, direct employment in the United States marine fisheries was only about 118,000 in 1966, and a large, though unknown, proportion of these fishermen are only part-time participants. The number of fishermen declined steadily from 1950 to 1964, reflecting a slight put persistent tendency toward large and more capital-intensive fishing units and a stable total catch, and has increased very slightly since then.

Considerable quantities of fish are harvested on the continental shelf adjacent to the United States by foreign fishermen. When this production is also considered, the total yields from over the continental shelf adjacent to the United States probably approach 10 billion pounds with an estimated value in the order of $605 million. While it is not certain that United States fishermen will ultimately capture any great share of the production now being taken by foreign fishermen, it must be considered in evaluating the resources currently extracted from the shelf areas of the United States.

2. POTENTIAL PRODUCTION

In terms of conflict with petroleum and mineral activities on the continental shelf it is equally important to assess potential yields. Recent articles by Alverson (1), Ahlstrom (2), Bullis (3) and Edwards (4) provided a basis for summarizing present thinking on the maximum sustained yield to be expected from United States shelf areas.

TABLE 4
NUMBERS OF UNITED STATES FISHERMEN

Region*	1965	1966
New England	19,435	18,518
Middle Atlantic	8,839	8,686
Chesapeake	18,996	18,810
South Atlantic	10,688	10,594
Gulf	25,571	25,309
Pacific (Washington, Oregon and California)	17,324	18,324
Hawaii	744	744
Alaska	17,454	19,412
Totals, exclusive of duplication	116,629	118,151

*Great Lakes and Mississippi regions excluded.
Source: U.S. Department of the Interior, Fish and Wildlife Service, *Fishery Statistics of the United States*, 1965, 1966. Statistical Digest No. 59, 60.

TABLE 5

ESTIMATED SUSTAINED CATCH CAPABILITIES FOR VARIOUS LATENT OR LARGELY UNUSED FISHERY RESOURCES
(millions of pounds)[1]

	Estimated Annual Catch Potential by Areas		
	ICNAF[2] Subarea 5	Middle Atlantic	Annual Totals
Fin Fish			
Flyingfish	6.6	11.0	17.6
Grenadiers	40.0	11.0	51.0
Anchovies	6.6	15.0	21.6
Sand Launce	6.6	2.2	8.8
Bluefin tuna	15.0	4.4	19.4
Yellowfin tuna	—	11.0	11.0
Skipjack	55.0	22.0	77.0
Little tuna and others	2.2	2.2	4.4
Swordfish	4.4	2.2	6.6
Sharks	77.0	66.0	143.0
Invertebrates			
Northern shrimp	55.0	—	55.0
Red crabs and others	2.2	2.2	4.4
Ocean quahogs	11.0	114.0	125.0
Surf clams	5.0	85.0	90.0

1 Estimates courtesy Keith A. Smith.
2 International Commission of Northwest Atlantic Fisheries.

The basic information for the East and Gulf coasts and the Pacific Northwest is presented in Tables 5, 6 and 7. In addition, Ahlstrom indicates an anchovy population in California waters in the order of 4 to 5 million tons, and from 1.4 to 2.4 million tons of jack mackerel and 2 to 4 million tons of hake. In addition, he forecasts a standing stock of at least 450 thousand tons of saury in offshore waters.

It would appear that the ultimate marketable potential yield of fisheries resources overlying the continental shelf off the United States is in the order of 50 billion pounds usually, or roughly ten times present United States production. Much of this would be very low-valued, and the bulk of it cannot be harvested profitably using present fishing techniques. Nevertheless, a gross economic yield of perhaps $2.0 to $2.5 billion annually is a potential that calls for both development and protection. It must be considered relevant in assessing the costs of pollution and physical interference that may emerge as mineral activities in the shelf assume greater importance. Morever, every regional area of present or prospective mineral activity has economically significant commercial fisheries. Though not considered specifically in this paper, the sport fisheries of each of these regions must also be considered important industries.

B. Non-living resources

1. DISSOLVED MINERALS

One of the popular parlor sports in currently fashionable amateur oceanography circles is to total the amounts of dissolved minerals in the world ocean

TABLE 6
1967 CATCHES AND LATENT FISHERY RESOURCE POTENTIALS OF THE GULF OF MEXICO AND SOUTHEASTERN ATLANTIC COAST
(million pounds)

	Gulf of Mexico		South Atlantic[1]		Total Expansion		Species of Greatest Potential
	1967 Catch	Estimated msy[2]	1967 Catch	Estimated msy[2]	1967 Catch	Estimated msy[2]	
Coastal pelagic fish	1,064	8,337	222	2,881	1,286	11,219	Herring, Sardine, Anchovy
Bottomfish (industrial)	88	4,852	9	3,611	97	8,463	Croaker, Spot, Seatrout
Bottomfish (food)	54	1,211	18	278	72	1,489	Snapper, Grouper
Midwater fish	0	2,148	1	91	1	3,120	Butterfish, Bumper, Scad, Harvestfish
Shellfish	257	3,807	80	3,480	337	7,287	Scallops, Squid, Lobster, Crab, Shrimp
High seas pelagic fish	0	893	1	1,096	1	1,989	Sharks, Tunas, Flyingfish, Dolphin
Total	1,463	21,248	331	11,434	1,794	33,567	

1 South of Cape Hatteras.
2 Maximum sustained yield.

TABLE 7

ESTIMATED SUSTAINABLE YIELDS (OREGON TO BERING SEA) FROM THE TEN MOST ABUNDANT COMMERCIALLY USABLE DEMERSAL FISH AND THE HARVEST LEVEL
(in thousand tons)

Species	Estimated Maximum Sustained Yield	Catch (highest)	Year	Catch High Five Consecutive Years (average)	Years	Catch 1966
Yellowfin sole	201-401	550	1961	340	1959-1963	140
Walleye pollack	169-338	260	1966	130	1962-1966	260
Pacific ocean perch	138-276	470	1965	271	1962-1966	315
Rock sole	136-272	8	1964	4	1962-1965	8
Pacific hake	150-270	175	1967	150	1966-1967 (only)	130
Arrowtooth flounder	82-164	39	1964	22	1962-1966	18
Flathead sole	35-70	11	1964	9	1962-1966	5
Dover sole	21-42	9	1963	7	1960-1964	4
Pacific cod	27-54	42	1966	27	1962-1966	4
Spiny dogfish	20-30	67	1944	37	1941-1945	4

waters. However meaningless the resulting numbers, they do impress people. A cold factual look produces the following, less sanguine, types of numbers (5). Suppose that we could, by some magic, remove all the dissolved minerals from a 55-gallon drum of seawater. The yield would be as follows: common salt, 13.25 pounds; magnesium chloride, 1.8 pounds; magnesium sulfate, 0.8 pounds; gypsum, 0.75 pounds; potassium sulphate, 0.4 pounds; calcium carbonate, 1 ounce; sodium bromide, 6 ounces; all other dissolved minerals, 0.2 ounces. Cast in more familiar terms, it would provide enough table salt for about 2 years of normal consumption for one person, enough magnesium to make an ingot weighing about 0.5 pound, and enough bromine to provide anti-knock additive for about 10 gallons of gasoline. To get $0.75 worth of gold, however, would require nearly a million drums of seawater.

Salt water extracts of salt, bromine, and magnesium are already providing commercially important additions to total production in the United States, and they represent, for all practical purposes, an inexhaustible supply. 1966 estimates indicate world production of sodium chloride of about 35 million tons (29% of total production); bromine, 102 thousand tons (70%); magnesium metal, 106 thousand tons (61%); and magnesium compounds, 690 thousand tons (6%). For the rest, even the concentrated effluent from a desalination plant represents an ore so lean as to suggest that it will be many thousand man-years of research before commercially feasible products emerge.

2. Hard Minerals on and below the Seabed

The most promising sources of hard minerals from the sea are submerged placer deposits that form a covering of unconsolidated material on the continental shelf. They are mainly confined to the inner edge of the shelf, and it is considered unlikely that major placer deposits will be found on the continental slope or beyond. Sand and gravel deposits are the principal output from this source at present, and there is a possibility of commercially exploitable quantities of gold, platinum and tin on the west coast and zircon on the east coast. In addition, marine phosphorite nodules are known to exist, chiefly on the upper parts of the slope.

Minerals may also be available from the substrate of shelves and slopes. Major prospects include coal, potash, phosphatic rock, iron ore, and bauxite. The highly publicized manganese nodules constitute the only known mineral resources of any economic interest beyond the continental slopes. The nodules are of considerable potential commercial interest, not only because of the manganese content, but because of the admixture of copper, cobalt and nickel. They are known to exist in quantity, but at depths sufficiently great to impose tremendous technological barriers to immediate development.

In brief, there can be no doubt that minerals useful to man are to be found on and below the seabed in quantities beyond his wildest dreams; but to locate, assess, recover and process them at prices competitive with land sources is still far beyond our capacity at present. The amount of actual hard mining in the sea, in the United States and the rest of the world, is of minimal proportions. The total value of offshore mineral production in the world, exclusive of oil, gas and sulfur, was estimated at about $700 million in 1967. About 30% of this came from United States waters, but it consisted almost entirely of sand, gravel and oyster shells. Offshore tin operations in Thailand and Indonesia accounted for more than 10% of the world's tin, and there have been promising operations for heavy mineral sands, particularly in Australia. The total number of firms actively engaged in production of minerals from the marine environment in 1967 was approximately 300.

The reasons for this relatively modest performance in the face of vast physical abundance are not hard to find. The sea is, after all, a hostile environment to man and materials. At the moment we simply do not have the technical capacity to delineate with any degree of accuracy the most promising areas to explore, nor do we possess the technology to operate conventional mining equipment at depths much beyond 100 feet, and then only in calm weather.

On the other hand, the research and technological advances required to permit man to operate safely and economically in the sea could also be employed to expand knowledge of and ability to use efficiently presently marginal land-based supplies. The most authoritative estimates available (6) suggest that present domestic and free world supplies of minerals from conventional sources should be adequate to prevent any significant increases in unit costs of minerals to the United States at least to the year 2000 (and probably well beyond for most). There is, however, some reason for uneasiness in the fact that some 40 of the 72 minerals regarded as essential to modern industrial economies must be imported by the United States at present, and the number seems destined to increase in the future.

On balance, therefore, it is difficult to see any logical economic reason to expect sharp expansion of hard mineral production from the seabed or below it for the next 20 to 30 years. On the other hand, there is sufficient evidence of commercial interest to suggest that even this lead time is within the planning horizon of larger and more forward-looking firms. Perhaps more important, major government programs to provide three-dimensional mapping of promising areas of the shelf, and to develop greater multi-purpose technology for marine operations could bring some materials into production much sooner. In any case, the time to develop a proper framework for protection of living resources is before, not after, the technological (and political) bases of mineral production are hardened.

C. Oil, gas and sulfur

The outlook for these interstitial fluids and soluble minerals is another story indeed. A 20-year forecast of tripled world demand, growing concern in many nations over the possible repercussions on oil supplies of the political instability of the Middle East, and a phenomenal rate of technological advance in offshore exploration and development have triggered a massive search for marine sources of oil and gas. Twenty countries are already producing or are about to produce oil and gas from offshore sources, and annual private investment outlays, now running more than a billion dollars, have been growing at nearly 18% per year in recent years. Current production has reached about 5.4 million barrels per day, about 16% of the daily world total output. Although the search for alternative energy sources and the development of oil shale and tar sand reserves may slow the growth of offshore oil production, it is generally expected that it will represent at least one third of total world production in 10 years.

In the process of pushing outward onto the continental shelf, the petroleum industry has surmounted one obstacle after another in developing exploration and development technologies. The ability to produce at 2,000 foot depths is within sight, extending the exploitable range well beyond the limits of the continental shelf proper. Offshore operations are necessarily more expensive than similar operations ashore, although the actual costs of exploration are lower and the offshore success ratio per drilled well is substantially higher than on land. As improved technology increases our capacity to do useful work under water and makes available more suitable materials and equipment, a continuing offset to the cost effects of the push into deeper waters may be expected.

At the moment, offshore petroleum extraction in United States waters is or soon will be operational in Louisiana, Texas, California and Alaska. There can be no doubt, however, that the ultimate range will be far greater. Exploration is proceeding apace along most continental shelf areas; and since oil companies are not eleemosynary or research institutions, production can be expected in many areas, at varying depths, and under both state and Federal jurisdiction.

The growth in demand for natural gas and the consequent pressure to prove and develop offshore sources has been equally startling. Present annual production is well in excess of 1 trillion cubic feet, and the trend has been sharply upward since the mid-1950's. Proved offshore reserves are now estimated to be in excess of 22 trillion cubic feet. Since gas is normally a joint product of exploration for oil (though transportation and distribution facilities are separate) the industry has a high growth potential.

Sulfur production — all from the Gulf Coast area — is presently above 1 million long tons, but geological and technical considerations suggest a much slower rate of growth for offshore sulfur than for oil and gas.

D. The importance of non-living marine resources

In summary, the problems of accommodating exploitation of mineral and living resources from the continental shelf and its waters are likely to arise in connection with oil, gas and sulfur production. Shallow water dredging for sand, gravel and oyster shells will continue to present nagging problems, but these involve the estuarine rather than the continental shelf environment. Recovery of dissolved minerals from sea water and desalination are also established economic competitors of fish and shellfish, but in these instances the operation is properly regarded as a land-based production unit, linked to the marine environment only by the possibility of chemical or thermal pollution from discharged waters.

The mining of hard minerals from the seabed and the recovery of nodules from its surface will doubtless come in the future, but for the moment any attempt to assess the type, area or nature of potential conflicts with living marine resources smacks of the old problem of the blind man looking in a dark room for a black hat that isn't there. When and if the economics of mineral supply make such operations feasible there should be ample lead time to define the area and nature of the activity and to evaluate the living resources that may be affected.

III. INTERACTION OF MINERAL AND PETROLEUM

The interaction of fisheries and mineral and petroleum exploration and production will obviously be dependent on the geographic and bathymetric distribution of such activities as they relate to the distribution and behavior patterns of the living resources. Major areas of conflict between harvesters of living resources and mineral and petroleum work on the shelf will result from:

(1) physical interference with fishing activities and (2) biological damage resulting from exploration and extractive processes.

A. Physical interaction

The following summary of types of fishing gear and of actual and potential types of mineral extraction techniques provides a basis for identifying the first type of interaction. Major fishing methods may be classified into the following categories: (1) gear for gathering sessile animals (shovels, tongs, rakes and dredges); (2) traps and barriers (pots, weirs); (3) hook and line techniques (hand lines, long lines, trolling) and (4) nets (seines, tangle nets, trawls, gill nets).

In addition to these there are several other modes that are relatively unimportant at the moment. These include wounding gears (harpoons, spears, explosives) and devices dependent on the physiological reaction of fish to physical or chemical stimuli (electricity, air bubbles, light and chemicals).

Of the four major fishing methods noted above, nets are by far the most important in quantities of fish produced. Of the various types of nets, purse seines and trawls dominate United States and world fisheries; tangle nets and gill nets are of decreasing importance, particularly in recent years. Of the hook and line systems, the long line gear used for Pacific halibut is of considerable importance, as is trolling which produces most of the Pacific silver and chinook salmon used in fresh and frozen forms. Traps and pots are employed widely for the harvest of crustaceans such as crabs, lobsters and shrimp. Almost all of the sessile animals — e.g., oysters, scallops and clams — are harvested with shovels, tongs, pumps, rakes or dredges.

It is apparent that all the major types of gear are likely to come in conflict with mineral or petroleum activities in the sea. Any fixed features placed on the seabed would obviously deny the immediate area to trawlers, although experience in the Gulf of Mexico indicates that trawling can be conducted in close proximity to activities involving mineral extraction if the surface marker is clearly visible or if very precise coastal positioning systems are available and in use. Trawls are certain to become involved in some degree, however, since this type of fishing extends over great areas of the shelf and the depths of fishing and areas of operation change seasonally. Pot fishing is similar in some respects, but since the gear is not moving along the seabed it can be operated in closer proximity to petroleum or mineral extractive operations. In plain fact, direct conflict between pot and long line fishermen, on the one hand, and trawlers on the other, presents as difficult a problem of physical accommodation as any present or likely seabed mineral operations.

Purse seining, trawling and trolling for pelagic species, which live and feed in mid or upper portions of the water column, are much less seriously affected by physical conflict with mineral and petroleum extraction. By definition, these fisheries are exploited with gear fished off the bottom, and it can be readily adjusted to clear low profile seabed installations.

If and when technology advances to the point where petroleum and gas, and — probably much later — hard mineral equipment can be made entirely subsurface, mid-water and surface fisheries will be largely free of physical interaction. Bottom fishing, on the other hand, will be made more difficult, since the visible surface evidence of operations below will be gone. In practice this simply means that high precision coastal navigation systems must be used by fishermen, and/or wider "buffer areas" around seabed mining installations must be agreed to, defined, and publicized.

It might be noted, parenthetically, that undersea mining, particularly if it employs "finished" subsurface installations *must* have precise positioning systems that are operational under all conditions. The problem is to make such systems available at a price that can be borne by fishermen operating in a highly competitive environment.

There have been approximately fifty collisions to date between oil rigs in the Gulf area and vessels of all kinds. In view of the generally unsatisfactory navigational equipment aboard fishing boats operating in the area, the record is not bad. The establishment of clearly defined fairways, better instrumentation and proper notification procedures can keep this hazard to minimal levels, although at some cost to both industries.

Another hopeful point is the technical flexibility that can be exercised on both sides. Gear conflicts in some fisheries have been resolved by appropriate divisions of available time on particular grounds. The principle could be extended to exploratory and even to some types of extractive activity. Seabed facilities, including pipelines, can be designed to minimize the possibility of fouling fishing gear when navigational errors occur. Some types of trawls may be set to fish above known areas of obstruction. The full possibilities of this type of mutual adjustment cannot be assessed until technological options available to seabed mineral extractors are known. The fact that all mineral exploration and recovery operations require permits from one or more government agencies could provide a means of insuring that these tradeoffs are considered before installation of major systems is sanctioned.

B. Biological damage

The second major area of conflict involves biological damage from exploitation or extraction processes used by petroleum and mining firms. Damage may result from: (1) seismic exploration involving underwater explosions or other sources of shock or pressure waves; (2) destruction or upheaval of sediments essential for food or cover; (3) siltation; (4) contamination from seepage, ruptured pipelines or wild wells; (5) direct destruction of sessile animals in or on the bottom sediments and (6) thermal pollution.

1. Seismic Exploration

Seismic exploration has been a source of some real damage and a vast set of rumors of much greater damage to fish life. "Conventional" seismic exploration, using electrically detonated charges of explosives (formerly dynamite or black powder; now usually nitro-carbo--nitrate) rapidly became the most extensively used technique, largely because of its consistently greater depth of penetration. Unfortunately, it is also the most likely to damage sea life. Research on other techniques that are harmless to fish has been proceeding so rapidly, however, that the problem may be largely a matter of historical interest.

Even conventional methods can be made reasonably safe. A series of closely controlled experiments confirms that fish with air bladders such as salmon, anchovy and sardines, are subject to damage from shots at ranges, horizontal and vertical, of 150 to 500 feet depending on the size of the charge, water depth, depth of the charge below the surface and bottom topography. Fish without air bladders, such as halibut, sole and flounders, plankton and invertebrates, such as clams, crabs and oysters, seem to be much less vulnerable, even at fairly close range.

Experiments involving industry and independent scientists from government or academic institutions have been conducted fairly recently in Alaska, (7) British Columbia, (8) Oregon (9) and Washington (10). In every instance, the researchers concluded that: fish damage was confined to a small area; damage could be reduced by restricting shooting when large concentrations of fish are visible on sonar; and total numbers of commercially useful fish killed were not large enough to be of serious concern. There is also considerable evidence from California and Oregon studies that the shots do not drive fish from the area.

In the words of Rulifson and Schoning, "when the number of shots, time, and lethal area are considered in respect of the vast amount of water and numbers of fish therein, the effect of seismic exploration off Oregon on the fisheries resources is indeed small . . . if seismic operations or procedures are carefully monitored and fish detection equipment is operating properly and effectively used the damage to offshore fishery stocks will be insignificant." Kearns and Boyd conclude: "In view of the area covered and number of shot points subjected to high velocity explosives, the resulting fish mortality was considered relatively light." The Oregon study notes that these conclusions are consistent with those of earlier studies in the Gulf area.

These are admittedly preliminary findings, and each investigator has gone to some pains to point out the need for more accurate estimates of damaged fish that sink and of possible damage to larvae and plankton, not visible in the usual experimental method. All are regarded as small, however. It should also be noted that of the total fish killed, less than 50% were species of commercial importance.

These findings, coupled with the fact that all states concerned and the Federal government require permits and observers for seismic work, suggest that the problem is well in hand. Continued advances in non-explosive techniques promise to reduce it still further. One industry publication recently reported that "in the space of one year the use of explosives as a sound source for sub-bottom seismic surveys has switched from 90% to 10%. Of the non-explosive sources, pneumatic systems now are most popular, while sparkers and hydraulic systems share the remainder." (9) In view of the rumors that still abound, education of the public to these facts is a matter of real importance.

2. Damage to Bottom Habitat

There is no similar base of information on which to assess the possible effects of siltation, crushing of crustaceans or destruction of bottom habitat by dredging. Sand, gravel and oyster shell dredging operations have caused all three types of damage in shallow bays, estuaries and beach areas, but ecological conditions in these areas are such that sessile resources are much more vulnerable than in open waters over the shelf. Moreover, an overwhelming proportion of these useful animals are found in sheltered shallow areas.

Again, the inability to predict where or how mining operations might be conducted makes it futile to generalize. When and if operations are contemplated on the bottom, the required permit should provide sufficient control to investigate what kinds of bottom disturbance would be caused, what specific species are found in the area concerned and how they might be affected.

3. CONTAMINATION

There is legitimate concern over the possibility of contamination from petroleum and sulfur extraction. In the case of petroleum, seepage of lubricants and other chemicals from the drilling and operating platforms is inevitable. Thus far, however, there has been no specific findings of significant damage to fish or shellfish. On the contrary, the Gulf oil rigs have proved to be an important attractor for several highly prized species of game fish. The possibility remains open, however, and continued monitoring of such sources of pollution is essential.

The possibility of spills from ruptured pipelines used to collect and transport oil from offshore wells can never be entirely eliminated. The same is true of uncontrolled wells. The magnitude of the threat is greatly reduced, however, by two factors. First, United States Geological Survey regulations covering all outer continental shelf lessees establish minimum requirements to insure control of wells during drilling, production, plugging and abandonment. Second, the companies themselves have a direct financial interest in minimizing losses of oil from wells or pipelines. Elaborate automatic control mechanisms for this purpose are now standard practice. Federal and state cooperation in maintaining effective safeguards is required, but such measures do not involve major controversy with the industry.

The general problem of spills is more serious with respect to tanker accidents, but this is unrelated to mineral operations on the continental shelf and is beyond the scope of this paper.

Nothing now in use or in prospect in oil or mineral extraction poses any threat of thermal pollution, with the possible exception of sulfur operations. It is highly likely, however, that nuclear power plants, some of them conceivably associated with mining operations, will be located on the seabed — partly for safety and partly to utilize the immense heat sink capacity of the ocean. It is conceivable that such operations, at least partially attributable to mining, could upset a local habitat enough to damage valuable fish or shellfish stocks, but only in a relatively shallow and partially enclosed area. They might, in some locations, actually improve productivity. In either case, the problem is much more directly associated with general power production than with mining.

C. Benefits from mining operations

The main external benefits which may accrue to the fishing industry from mineral and petroleum production on the shelf stem from the technology developed pursuant to these activities. The oil industry's needs and response thereto have already produced widely usable improvements in underwater exploration techniques and in man's capacity to work on the seabed. It is precisely this kind of broad-based technology that is needed to enhance progress toward the ultimate objective of moving from a hunting to a harvesting concept of fishing. It is even possible that in dredging for heavy metals, harvesting of mollusks could be a profitable by-product.

It now seems clear that a major national and international effort to chart the ocean bottom and to core in areas of prime interest will be necessary if undersea mining other than gas and oil is to gain real momentum. Such exploration activities will provide considerably more knowledge of the distribution of animals which inhabit the seabed sediments and of their potential as food sources for man. Underseas mining facilities may become highly useful instrumented stations for sensing the distribution of fish or changes in the environment affecting abundance and concentration.

IV. CONCLUSIONS AND A WORD OF WARNING

It seems in order to end this discussion on a fairly optimistic note. The most important point to be stressed is the need for bilateral consideration of alternatives and adjustments. Left to its own devices, the fishing industry would doubtless choose to cut its losses by eliminating ocean mining completely. By the same token, the lowest cost solution from the standpoint of petroleum or mining operators might well involve moderate to serious damage to living resources, since the losses would accrue to someone else. But if either or both are induced (or compelled) to view the problem as one of maximizing the aggregate net economic benefit from both sets of activities, the broader public interest can be served at a total cost of accommodation that is not likely to be a major factor to either group. Given, for example, properly spaced drilling platforms, properly defined fairways, and access to reasonably priced precise positioning equipment, there is no reason to believe that the petroleum industry would impose particularly heavy burdens on the fishing industry because of physical incompatibility of operations. By the same token, cooperation between government and industry in establishing firm procedures to minimize the areas affected by spills and ruptures of petroleum transportation and storage equipment provides quite complete protection against major damage at a relatively small and predictable cost to industry.

It must be borne in mind, however, that these rather sensible methods of accommodating conflict did not come into being automatically. The potential threat to the fisheries of completely unrestricted seismic exploration, drilling, and production by the petroleum industry was real — and it probably would have imposed substantial and quite unnecessary costs on the fishing industry and the general public. Granted that the resulting public outcry was probably based on quite erroneous estimates of the nature and magnitude of the threat, it *was* effective in forcing acceptance of a considerable measure of responsibility by the petroleum industry. The result was, predictably, a successful effort by a highly competent, research-oriented industry to attack the sources of the conflict in order to reduce its own costs; and, in the process, those of the public generally.

In short, protection of the marine environment is almost never an automatic result of the operation of market forces alone. But in conjunction with intelligent public policy, the self interest of those exploiting all types of resources on or above the continental shelf can be brought into reasonable consonance while retaining generally acceptable boundary lines between private activity and decision-making by government. The preservation of environmental quality is, like liberty, the product of constant vigilance.

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